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Fair and Social-Aware Message Forwarding Method in Opportunistic Social Networks

Bidi Ying, Kai Xu, and Amiya Nayak

***Abstract*—In opportunistic social networks, most of the existing store-carry-forward routing mechanisms have severe problems with unfair traffic distribution among nodes and unfair delivery success ratio for individuals. To address these issues, we propose a novel protocol, called fair and social-aware message forwarding (FSMF), for opportunistic social networks. FSMF first introduces a Markov chain model of users' social ties to evaluate users' social relationship and then formulates the problems of unfair traffic distribution and unfair delivery success ratio. Moreover, FSMF limits the number of message copies and restricts the number of forwarding copies according to users' social ties in order to improve fairness. The simulation results show that our protocol has a lower standard deviation of traffic distribution and delivery success ratio.**

***Index Terms*—Opportunistic social networks, fairness, message forwarding.**

I. Introduction

IN OPPORTUNISTIC Social Networks (OSNs), social mobile nodes exchange data with their encountered nodes, which is the basis of the store-carry-forward routing mechanism proposed in [1]. Recently, researchers have focused on investigating social tie patterns, such as popularity and community, as the selection metrics of relay nodes to deliver data to destinations for designing efficient data forwarding strategies [2]–[4]. These relay nodes which have strong social relationships usually end up in having heavy traffic load [5]. This phenomenon could lead to unfair traffic distribution. Also, there is a high probability that messages from a popular user can reach its destination successfully; on the contrary, users with weak social ties will experience low success of delivery [4]. This causes unfair delivery success rates among individuals. Unfortunately for OSNs, the unfairness can cause several problems with the existing message forwarding strategies. This is because (1) nodes not having enough resources to manage the traffic load could experience frequent buffer overflow [5]; (2) popular nodes are easy target of attacks [5]; (3) the unfairness in delivery success can become a deterrent for a nodes participation in the network. Soelistijanto [6] also show that absolute traffic fairness could result in the deterrent of delivery efficiency; however, high delivery efficiency leads to unfair node traffic loads. Jedari et al. [9] pointed out that selfish nodes refuse to forward messages received from other nodes or share their resource with them because of different reasons, such as limited resources, privacy concerns [4], or monetary cost. These selfish behaviors can highly degrade the efficiency of message forwarding [9]. Thus, effective and incentive mechanisms, which are classified into three categories Tit-For-Tat(TFT)-based, reputation-based and credit-based schemes, are investigated for cooperation with each other in message delivery [9]. Jedari *et al.* [9] have also pointed out that the TFT-based schemes cannot provide fairness if encountered nodes do not have the same number of messages to exchange; the reputation-based schemes are challenging for fairness in distributed OSNs because nodes cannot observe the behavior of each other thoroughly; the credit-based schemes cannot provide fairness of traffic and delivery success among nodes because these schemes maximize selfish nodes profits (e.g., maximizing selfish nodes utilities).

To address the above issues, we propose a fair and social aware message forwarding scheme to improve delivery efficiency and fairness in OSNs. To encourage more nodes to participate in message delivery, a credit of the social tie is rewarded to nodes. A Markov chain model is used to investigate and update nodes social ties. We then analyze the problems of fairness of delivery success ratio and fairness of traffic distribution. Finally, we design our protocol to address the above problems by introducing nodes social ties and message priorities. Simulation results show that our protocol achieves fairness in traffic load distribution and delivery success ratio, while maintaining a lower routing overhead and a higher delivery success ratio compared to its counterparts.

II. Social Ties

The most impact on social ties in our protocol is the frequency of interacts. We define $ST_f(t_j)$ be the value of the social ties of user f at time t_j. If user f has not any interacts after a period, its social tie will decrease; if some interacts occur in user f, its social tie will increase. The larger the value of $ST_f(t_j)$, the stronger the relationship user f has. Since forwarding messages consume nodes resource (e.g., energy, bandwidth, routing overhead), some selfish nodes may not cooperate to forward it. To encourage a node to participate in message forwarding, the node should be rewarded with a credit for its forwarding behavior. In other words, the strength of the nodes social tie should be enhanced. Thus, we build a Markov chain model to analyze a node's social tie changes

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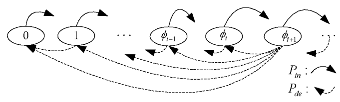

Fig. 1. Markov chain model of a node.

in the network. A state in the model represents a value of the node's social tie. The transition probabilities of the model represent all actions that change values of a node's social tie (i.e., increase or decrease), such as being rewarded a credit. The initial state in the model is represented by the value of the social tie being zero, and the final state is reached when the value of the social tie runs out and is equal to zero. Fig. 1 shows the Markov chain of a node with different behaviors, where P_{de} and P_{in} are the probability of decreasing its credits, and the probability of increasing its credits, respectively. The two cases for a state change are as follows:

Case 1 (Credit Decreased Caused by a Period Without Interactions): Due to non-interactions over a period, the social tie will be decreased, and thus, the transition probability $P_{de:j\to i}(t_j, t_i)$ from state ϕ_j to ϕ_i (where $i > j$) without interactions during a period is calculated as:

$$P_{de:j\to i}(t_j, t_i) = \gamma^{t_i - t_j} \tag{1}$$

where $\gamma \in (0, 1)$ is the aging parameter decreasing the value of social ties, and t_j is the time when reaching the state ϕ_j, and t_i is the time when moving to the state ϕ_i.

Let $ST_f(t_j)$ be the value of the social ties of node f at time t_j. Thus, the social ties will be updated as follows:

$$ST_f(t_i) = ST_f(t_j) - P_{de:j\to i}(t_j, t_i) \times ST_f(t_j) \tag{2}$$

Case 2 (Credit Increased Caused by Forwarding Messages): A node can improve its social tie by forwarding a message directly as the positive action is rewarded as a credit. Let $\alpha \in (0, 1)$ be a scaling parameter associated with rewarding the credit of forwarding a message, P_{go} be the probability of the node whose social tie is higher than the previous forwarder, we then have the probability $P_{in:i\to i+1}(t_i, t_{i+1})$ of moving from ϕ_i to ϕ_{i+1} as an increase of its social tie as follows:

$$P_{in:i\to i+1}(t_i, t_{i+1}) = P_{go}\alpha - \gamma^{t_i + 1 - t_i} \tag{3}$$

After node f forwards a message at time t_{i+1}, its social tie should be updated with:

$$ST_f(t_{i+1}) = P_{in:i\to i+1}(t_i, t_{i+1}) \times ST_f(t_i) + ST_f(t_i) \tag{4}$$

III. Fair and Social-Aware Message Forwarding (FSMF) Protocol

A. Motivation

Recently, social ties are investigated to provide efficient data forwarding strategies in OSNs. It is obviously that nodes with strong social ties carry the majority of the traffic, hence producing an unfair load distribution [9]. Given a period Δt, let us define $TOut_f$ to be the total number of outgoing messages from node *f*. We can then have the outgoing traffic load of node f as follows:

$$TF_f = TOut_f \times B \tag{5}$$

where B is the size of the message.

We use the standard deviation (represented as σ_{TF}) to represent the fairness of the traffic distribution. If we have a low standard deviation, it means that the traffic distribution tends to be close to the average traffic load. In other words, it has a fair traffic distribution. To achieve fair traffic distribution, we should minimize σ_{TF}. In other words,

$$\sigma_{\min} = \min(\sigma_{TF}) = \min\left(\sqrt{\frac{\sum_{f=1}^{N}\left(TF_f - \overline{TF}\right)^2}{N-1}}\right) \tag{6}$$

where $\overline{TF}$ is the average outgoing traffic load, and N is the total number of nodes in the network.

If a person is popular with many people, he/she usually has many social ties with others [10]. Thus, messages owned by nodes with strong social ties are usually easy to reach their destination successfully. In other words, nodes with weak social ties may have a lower delivery success ratio. To address this issue, we should make these nodes have higher delivery success ratio (defined them as Dsr_{weak}). That is,

$$Dsr_{\max} = \max(Dsr_{weak}) \tag{7}$$

Therefore, our goal is to try to find a way to satisfy the Eq. (6) and (7), in order to solve the above issues.

B. FSMF

Before given details of our protocol, we first formulate the problems of the Eq. (6) and (7).

1) Fairness of Traffic Distribution: To address this issue, the direct way is to limit the number of outgoing messages forwarded by the user having strong social ties. Thus, our protocol limits the number of forwarding messages. This could reduce the heavy traffic load from nodes which have strong social ties. To reach the aim of Eq. (6), FSMF has to meet the following requirements:

CM

$$FOut_f(m, t_i) = CCM_f(m, t_i) \times e^{-\left(2 - \frac{L(m,t_i)}{L_{\max}(m)} - \frac{ST_f(t_i)}{ST_{\max}}\right)} \tag{8}$$

$$ST_f(t_i) < ST_r(t_i) \tag{9}$$

CM

where $FOut_f(m, t_i)$ represents the number of messages sent out by node f at time t_i, $CCM_f(m, t_i)$ is the current number of message *m* from node *f* at time t_i, $L(m, t_i)$ is the remaining life of message *m* at time t_i, $L_{\max}(m)$ is the maximum life of the message *m*, $ST_r(t_i)$ is the value of social tie of node *r* who receiving the message *m* from node *f* at time t_i.

Eq. (8) indicates that the number of forwarding messages is dependent on the current social ties and the remaining life of the message. The stronger the node f has the social tie, the fewer the messages are send out. This reduces the traffic load of node *f*. There will be greater number of outgoing messages if those messages have shorter remaining life. Eq. (9) means that if $ST_f(t_i) < ST_r(t_i)$, node *f* sends $FOut_f(m, t_i)$ message copies to node *r*. This way improves the delivery success ratio.

2) Fairness of Delivery Success Ratio: Since the fairness of delivery success ratio is mainly caused by the difference of social ties of each node, FSMF introduces a function $\Psi(CM_f(m,t_i))$ to improve the fairness of delivery success ratio. In other words, Eq. (7) turns into $Dsr_{\max} = \max(\Psi(CM_f(m,t_i)))$ which must satisfy the following requirements:

$$P_f(m,t_i) = \frac{ST_{\max} - ST_f(t_i)}{ST_{\max} - ST_{\min}} \tag{10}$$

$$CM_f(m,t_i) = CM_{avg} \times P_f(m,t_i) \tag{11}$$

where $P_f(m,t_i)$ represents the priority of message *m* owned by node *f* at time t_i, $ST_{\max}$ is the maximum value of social ties in the network and $ST_{\min}$ is the minimum value of social ties in the network, $CM_f(m,t_i)$ means the number of copies of message *m* originated by node *f* at the time t_i, CM_{avg} represents the number of message copies generated on average in the network, and the value is generally preset by the network. ST太大， Pf会变小

Eq.(10) indicates that messages generated by nodes having a few friends to have a higher priority delivery. This could reduce the waiting time occurred in the buffer, and avoids the message loss by expiration. Eq.(11) indicates if a node has more copies of message then they are treated with higher priority. Therefore, there is a high probability that these messages could reach their destinations.

3) Details of Our Protocol: Our protocol includes two stages: a message spraying stage and waiting stage. Before given details of these two stages, we firstly provide the definition of a forwarding-copy rule.

Definition of the forwarding-copy rule: if a node *f* has $CCM_f(m,t_i)$ copies of a message *m*, it sends the $FOut_f(m,t_i)$ $(= CCM_f(m,t_i) \times e^{-(2-\frac{L(m,t_i)}{L_{\max}(m)}-\frac{ST_f(t_i)}{ST_{\max}})})$ copies to another node which does not have the same message.

In our protocol, during the message spray stage, before node *s* delivers his/her message *m* to the destination (*d*), it firstly copies $CM_s(m,t_i)$ message *m* at time t_i. When node *s* encounters node *k* which does not have the message *m*, it checks their social ties $ST_s(t_i)$ and $ST_k(t_i)$. If $ST_s(t_i) < ST_k(t_i)$, node *s* sends $FOut_s(m,t_i)(= CM_s(m,t_i) \times e^{-(2-\frac{L(m,t_i)}{L_{\max}(m)}-\frac{ST_s(t_i)}{ST_{\max}})})$ copies of message *m* to node *k*, and then sprays the remaining copies $(= CM_s(m,t_i)$-$FOut_s(m,t_i))$ following the forwarding-copy rule if other nodes whose social ties are larger than its social ties. This process will be repeated until node *s* has only one copy of message *m*. For example, node *s* encounters node *n* whose social tie is larger than node *s*'s social tie at time t_j, node *s* sends $FOut_s(m,t_j)$ copies of message *m* to node *n*, where $FOut_s(m,t_j) = CM_s(m,t_i) \times (1 - e^{-(2-\frac{L(m,t_i)}{L_{\max}(m)}-\frac{ST_s(t_i)}{ST_{\max}})}) \times e^{-(2-\frac{L(m,t_j)}{L_{\max}(m)}-\frac{ST_s(t_j)}{ST_{\max}})}$. After receiving these $FOut_s(m,t_i)$ copies, node *k* sends $FOut_k(m,t_j)$ $(= FOut_s(m,t_i) \times e^{-(2-\frac{L(m,t_j)}{L_{\max}(m)}-\frac{ST_k(t_j)}{ST_{\max}})})$ copies to another node whose social tie is larger than $ST_k(t_j)$, and then distributes the remaining copies as node *s* does. Node *n* sends $FOut_n(m,t_{jj})$ $(= FOut_s(m,t_j) \times e^{-(2-\frac{L(m,t_{jj})}{L_{\max}(m)}-\frac{ST_n(t_{jj})}{ST_{\max}})})$ copies to another node whose social tie is larger than $ST_n(t_{jj})$, and then distributes the remaining copies as node *s* does. Receiving copies of message *m*, nodes do the same process until all of them have only one copy of message *m*.

When nodes have only one copy of message *m*, they enter a waiting stage. During the waiting stage, when encountering a node whose social tie is larger than itself, it exchanges the only copy of message *m* to the node. This process will be repeated when the message *m* reaches the destination or the life of the message *m* is expired. Different from the existing protocols [1], [8], it could reduce the waiting time. Thus, it could improve the efficiency of message delivery.

This protocol has three advantages: (1) it does not need to wait for encountering the destination when delivering messages which, in turn improves the delivery efficiency; (2) it limits the number of copies which as a result reduces routing overhead, and improves the fairness of traffic distribution; (3) it further improves fairness by using message priority.

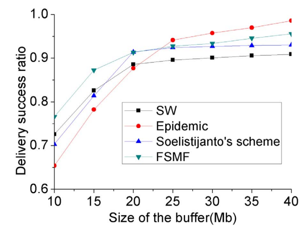

Fig. 2. Delivery success ratio vs size of the buffer.

IV. Performance Evaluation

In our simulation, we evaluate our protocol using the ONE simulator [7], a discrete event simulator for opportunistic social networks. In this simulation, the values of users original social contacts are generated randomly between (1, 10) by the system and updated using Eqs. (2) and (4) as interactions happen. For the users mobility model, we use random-way point to simulate 126 social nodes trajectories in a map of 4500m*3500m. Their speeds are in the range of [1.5 - 50] km/h. The communication range of each users portable device is 10m, and the size of the message is between 500KB and 2MB. The simulation takes 12 hours for each run. Each point in the following figures is the average of 100 runs around the map. We track the performance with three metrics: (1) individual fairness expressed as an average delivery success ratio, where delivery success ratio is the number of request messages reaching the destination / the number of request messages; (2) delivery efficiency, measured by the route overhead ratio, where route overhead ratio is (total number of delivery messages the number of messages reaching the destination) / the number of messages reaching the destination; (3) fairness of delivery success ratio, which is reflected in the standard deviation of delivery success ratio; (4) traffic distribution fairness, which is reflected in the standard deviation of traffic. We evaluate our protocol in different cases, and compare them with SW [1], Soelistijantos scheme [6], and Epidemic [8].

Fig. 2 illustrates how the delivery success ratio varies with the buffer size. When the size of the buffer is larger than 20Mb, the delivery success ratio in our protocol remains above 0.9.

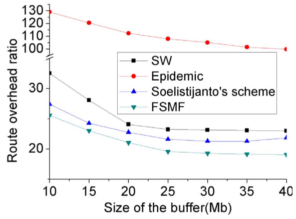

Fig. 3. Route overhead ratio vs size of the buffer.

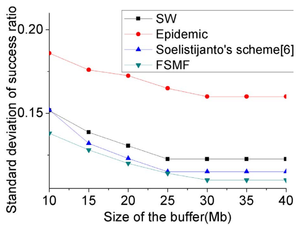

Fig. 4. Standard deviation of success ratio vs size of the buffer.

Compared to SW and Epidemic, our protocol has a higher delivery success ratio, and these values can be quite acceptable for social users. The main reasons are: (1) our protocol always chooses a node which has strong social ties as a forwarder, and thus improves the success of message delivery to its destination; (2) our protocol introduces message priority, and thus enables data held by a node which a has low social tie to have a higher delivery priority. This achieves the fairness and thus improves the delivery success ratio. Also, the delivery success ratio in three protocols increases gradually and then remains stable with the increase in the buffer size. The main reason for that for smaller buffer sizes there are frequent buffer overflows.

Route overhead ratio varying with the buffer size can be seen in Fig. 3. As the buffer size increases, curves of these protocols are going down slowly. When the size of the buffer is 25Mb, the route overhead ratio in FSMF, SW, Soelistijantos scheme, Epidemic are 19, 23, 21, 107, respectively. Thus, we can see that our protocol has the lowest route overhead ratio. The main reason for that is our protocol limits message copies and thus reduces routing overhead.

Fig.4 provides the fairness of delivery success ratio. It is clear that our protocol has the lowest standard deviation for the delivery success ratio. The main reason is that nodes which have low social ties have a strong message delivery priority.

Fig.5 shows the fairness of traffic distribution. When the size of the buffer is 35Mb, the standard deviation of outgoing traffic in our protocol is 5.6, while that in SW, Soelistijantos scheme [6], and Epidemic are 10.1, 8.4, 47.4, respectively.

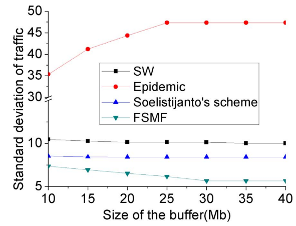

Fig. 5. Standard deviation of traffic vs size of the buffer.

Thus, it proves that our protocol has a superior fairness of traffic load as it has a lowest standard deviation of the traffic distribution.

V. Conclusion

To improve the fairness of traffic load and fairness of individual, we describe a fair and social-aware message forwarding mechanism for opportunistic social networks. Simulation results show that our protocol has better delivery efficiency, lowest routing overhead, and exhibits fairness in traffic distribution and delivery success ratio when compared with its counterparts.

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